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METHOD FOR MEASURING BRASH ICE THICKNESS WITH IMPULSE RADAR.(U)

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C.R. Martinson and A.M. Dean, Jr.

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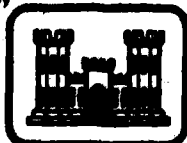
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PREFACE

This report was prepared by Carl R. Martinson, Civil Engineering Technician, and by Arnold M. Dean, Jr., Electronics Engineer, of the Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The project was initiated and sponsored by the U.S. Coast Guard Research and Development Center under Interagency Agreement Z51100-0-00003.

Dr. Steven Arcone and Austin Kovacs of CRREL technically reviewed the manuscript of this report.

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METHOD FOR MEASURING BRASH ICE THICKNESS WITH IMPULSE RADAR

Carl R. Martinson and Arnold M. Dean, Jr.

INTRODUCTION

From 4 to 6 March 1980 a field investigation of brash ice thickness measurement with the CRREL subsurface impulse radar system was conducted on board the USCGC Bristol Bay. The objectives of the mission were 1) to determine the feasibility of using the radar system to measure brash ice thickness from a moving icebreaker and 2) to supply brash ice thickness data to Coast Guard researchers who were testing the resistance of a ship to passage through brash ice. The tests were conducted in the St. Clair River near Dickinson Island and in Lake Erie on the eastern side of Pelee Island.

EQUIPMENT

The radar system consists primarily of a control unit with a microprocessor, an analog tape recorder, a graphic recorder and an antenna. The control unit and recorders are shown in Figure 1. The antenna (a shielded bow-tie dipole) can be seen in the field mount in Figures 2, 3 and 4.

The control unit manages the other units of the radar system through timing, data manipulation and power conversion. It allows the operator to select the sampling and recording rates, the time gain and the data manipulation parameters and to monitor the signal received during data collection. The data are fed through a microprocessor, which uses a real-time digital filter. The microprocessor can use any of several programs, depending on the type of noise to be eliminated and the medium to be profiled (Dean 1980).

The tape recorder stores the analog signal that it receives from the control unit. After the data are recorded, they are played back through the control unit to the graphic recorder, which produces a printout for interpretation. This graphic recorder can record directly if the data are collected at a very slow speed (i.e. when the ship is moving at less than 2 knots). During the tests for this project, direct graphic recording was



Figure 1. Radar units on the ship's bridge. From left to right: graphic recorder, tape recorder and control unit.



Figure 2. Antenna mount.

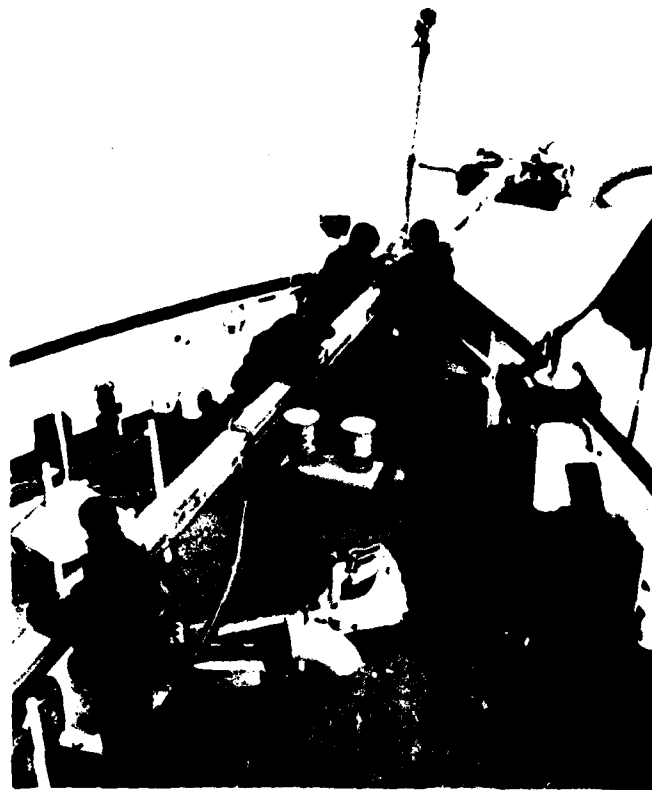


Figure 3. Crew members moving antenna into position.



Figure 4. Ship's track used for test area.

not desirable, as the ship was traveling too fast for the graphic recorder to be able to produce a useful printout in the direct record mode.

The antennas used on the icebreaker were designed for aerial data collection. Since they were used in the same fashion as they would be during aerial use, i.e. suspended above the ice, they proved to be suitable for this project. Antennas designed to be towed over the surface were not used because they have been shown to introduce severe noise and reflection into the data (Dean 1977). Antennas of newer design are better shielded but not to the extent of the airborne model. Surface-towed models have a larger spatial sensitivity than does the airborne model, and the ship's hull would have created interference. The spatial sensitivity of the two-unit antenna as configured for this project gives a somewhat elliptical projection on the surface, with the major axis of the ellipse perpendicular to the direction of travel. This orientation was chosen to reduce the possibility of interference from the ship's hull. With the antenna suspended 4.0-4.6 m above the ice and its 3-db aperture assumed to be 30-50°, the minor axis on the surface is about 2.2-4.3 m long (Dean 1979).

METHODS

The transmitting and receiving antennas were mounted side by side for this study. The two antenna units were held as close to horizontal as possible, since as they move from the horizontal, the signal strength is reduced or lost because the signal is reflected away from the receiver. This results in fewer identifiable points on the printout. The antenna can be off by approximately 15° from the horizontal with no detrimental effect on the data.

Because metallic objects close to the antenna cause interference, the antenna was mounted on a fiberglass I-beam (Figs. 2 and 3). The I-beam was then extended in front of the ship until it was approximately 3 m from the bow and 4.0-4.6 m above the ice. In this position there was no significant reflection from the ship's hull.

The rest of the system was operated from the ship's bridge. This location provided a shelter for the instruments and an unobstructed view of the antenna. A sheltered location such as the bridge is necessary; if the

instruments are subjected to freezing temperatures or wet weather, they may malfunction.

Initially, some ice thicknesses were measured to calibrate the radar data. These thicknesses, obtained through ground-truth measurements, provided an aid in determining proper control unit settings. This information was then applied to other areas on the assumption that the brash ice maintains the same range of thickness.

Ground-truth measurements were made with a device resembling a large, collapsible umbrella. The device, with arms closed, was jammed through the brash ice (Fig. 5). The arms were then extended and the device lifted until contact was made with the underside of the ice cover. The thicknesses for ten measurements at six ground-truth locations ranged from 0.35 to 1.7 m.

After the ice thickness was measured manually, the ship passed over the area to profile the ice thickness and record the information on tape. A reference mark was recorded on the tape when the antenna was directly over a point of ground-truth measurement.

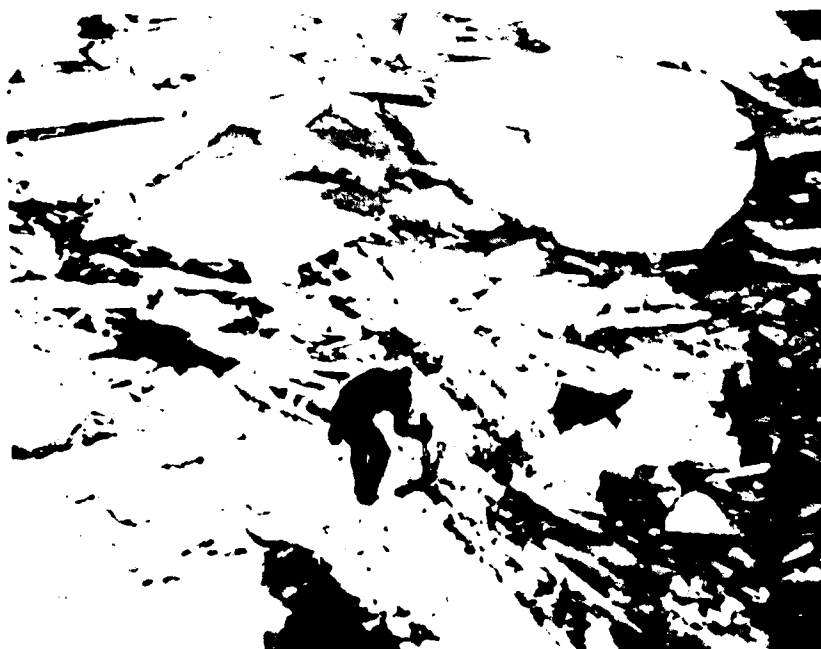


Figure 5. Measuring brash ice thickness.

The ice-to-water ratio of the brash ice was approximated as follows. It is known that the round-trip impulse rates are approximately 4 ns/ft and 18 ns/ft for freshwater ice and fresh water, respectively. Suppose ground-truth measurements show the ice to be 3 ft thick and the radar-signal travel time at that location is about 33 ns. Now,

For water: $3 \text{ ft} \cdot 18 \text{ ns/ft} = 54 \text{ ns}$

For ice: $3 \text{ ft} \cdot 4 \text{ ns/ft} = 12 \text{ ns}$.

If the unknown x is the percentage by volume of ice in the medium, then

$$x(12) + (1-x) 54 = 33$$

or

$$x = 0.5$$

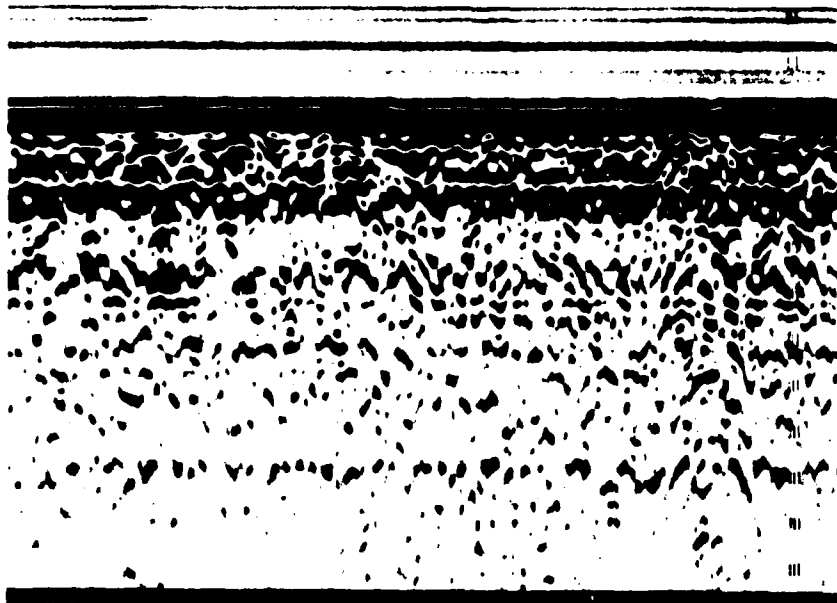
and the mixture is assumed to be half water and half ice.

RESULTS

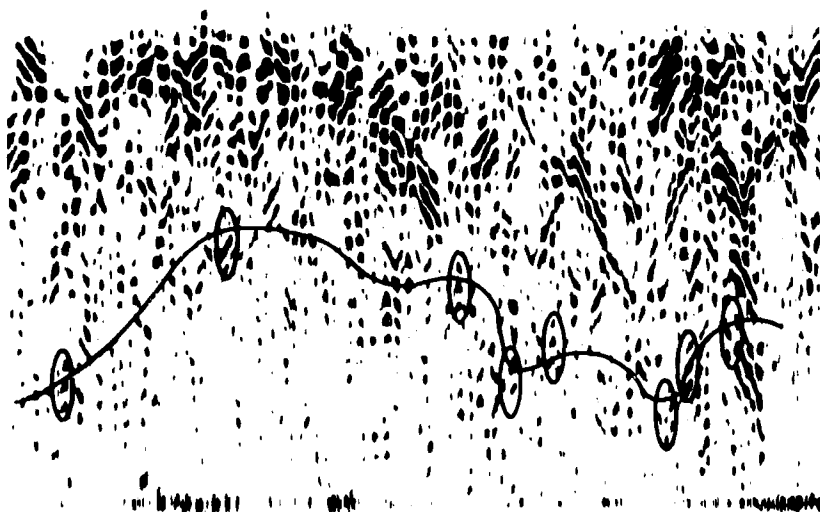
Because of the mild winter and a decline in winter navigation, the ice was not suitable for testing. Therefore it was necessary to create the required conditions with the Bristol Bay by making several passes through the same track. The ship produced a layer of brash that ranged up to approximately 1.7 m (as determined by ground-truth measurements). The ice-to-water ratio was approximately 1:1. Typical generated brash conditions may be seen in Figures 4 and 5.

Most of the usable data were collected when the ship's speed was 3-4 knots. The unprocessed data (Fig. 6a) are virtually undecipherable, while the processed data (Fig. 6b) are interpretable. Some of the data were recorded when the ship's speed was 10 knots (Fig. 7). At this speed, the data on the printout are greatly condensed, and interpretation is more difficult. The antenna mount caused a slight vibration of the antenna that, although noticeable in the data, was not significant and did not affect the interpretation.

Of the six ground-truth points surveyed, the ice thicknesses at five were interpretable on the printout. The sixth point had too much signal scatter to provide enough recognizable reflection to determine the ice thickness. Of 12 points marked for interpretation as sampling points, 11 were interpretable when the ship's speed was 3-4 knots. Five points recorded for interpretation when the ship's speed was 10 knots were not interpreted. As previously mentioned, data recorded at this speed are more difficult to extract, and the cost-to-benefit ratio of interpreting these five points was too high.



a. Before signal processing.



b. After signal processing. The circled items indicate targets on the lower extremity of the ice. A smooth curve is then drawn through these points to represent the bottom of the accumulation.

Figure 6. Graphic representation of brash ice. The ship's speed was 3-4 knots.

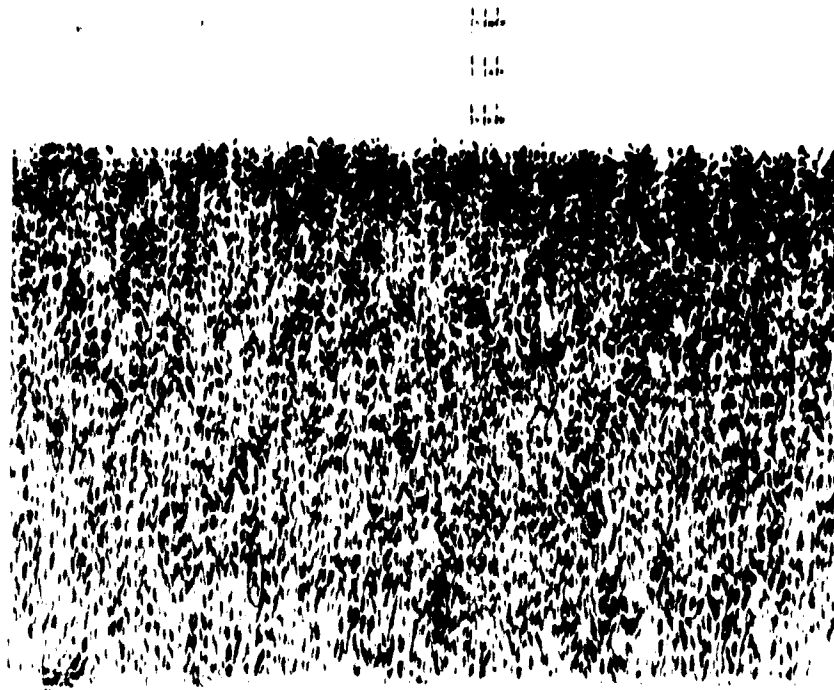


Figure 7. Processed data collected at 10 knots.

There is a possibility that some unusually deep ice, greater than 1.7 m, was not seen. To provide better resolution and because no physical measurement exceeded 1.7 m, the control unit time sampling window was set to view to a depth of only about 1.8 m.

When recording data with the antenna suspended in air, the radar is actually recording reflected signals from a broad area. Within this area, the ice depth can vary, as can the size of individual ice pieces. A non-uniform ice-water mix will cause variation in the dielectric constant. Therefore, it is necessary to interpret the data as a range of ice thickness.

Table 1 is a list of sampling points and their corresponding ice thicknesses. The time range is the flight time of the transmitted signal through the ice. For this ice, the time of flight varied from 9 to 12 ns/ft and averaged 10 ns/ft.

Table 1. Time and ice thickness ranges for each sampling point.

<u>Sampling point</u>	<u>Time range (ns)</u>	<u>Ice thickness range (it)*</u>
1	Uncertain	--
2	25-35	2.5-3.5
3	45-50	4.5-5.0
4	40-55	4.0-5.5
5	40-55	4.0-5.5
6	35-45	3.5-4.5
7	35-45	3.5-4.5
8	35-45	3.5-4.5
9	30-45	3.0-4.5
10	30-40	3.0-4.0
11	30-45	3.0-4.5
12	35-45	3.5-4.5

*Average time of flight = 10 ns/ft

CONCLUSIONS

Radar profiling of brash ice thickness from a moving icebreaker is feasible. Anticipated interference problems never developed, probably because metal objects were kept away from the antenna and because the area was apparently low in radio frequency interference. The ship also maintained radio silence while a test was in progress.

If this method is to be used, more ground-truth data should be collected. Generally only one ground-truth measurement was made within the viewing area of the antenna at a given point. Since periodic ground-truth data are important in establishing the reliability of radar-collected data, it would be advantageous to take enough measurements to obtain an accurate average flight time of the radar signal for the ground-truth area. If several measurements are taken and they are consistent, then that would be

enough for an area, but if they varied by several feet, then more measurements should be made. The necessary amount of ground-truth information depends on the variation of brash ice thickness and density.

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